



Microwave photonic phase shifter based on tunable silicon-on-insulator microring resonator

Pu, Minhao; Liu, Liu; Xue, Weiqi; Frandsen, Lars Hagedorn; Ou, Haiyan; Yvind, Kresten; Hvam, Jørn Märcher

Published in:
2010 Conference on Lasers and Electro-Optics (CLEO) and Quantum Electronics and Laser Science Conference (QELS)

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Pu, M., Liu, L., Xue, W., Frandsen, L. H., Ou, H., Yvind, K., & Hvam, J. M. (2010). Microwave photonic phase shifter based on tunable silicon-on-insulator microring resonator. In *2010 Conference on Lasers and Electro-Optics (CLEO) and Quantum Electronics and Laser Science Conference (QELS)* (pp. 1-2). IEEE.
<http://www.cleoconference.org/>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Microwave Photonic Phase Shifter Based on Tunable Silicon-on-Insulator Microring Resonator

Minhao Pu¹, Liu Liu¹, Weiqi Xue¹, Lars H. Frandsen², Haiyan Ou¹, Kresten Yvind¹ and Jørn M. Hvam¹

¹DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, DK-2800 Lyngby, Denmark

²NKT Photonics, Blokken 84, DK-3460 Birkerød, Denmark

mipu@fotonik.dtu.dk

Abstract: We demonstrate a microwave photonic phase shifter based on an electrically tunable silicon-on-insulator microring resonator. A continuously tunable phase shift of up to 315° at a microwave frequency of 15GHz is obtained.

©2010 Optical Society of America

OCIS codes: (060.5625) Radio frequency photonics; (130.3120) Integrated optics devices; (230.5750) Resonators;

1. Introduction

Microwave photonics for processing microwave and millimeter-wave signals in the optical domain has lately received increasing interests [1]. Photonic components, providing compact size, large bandwidth, fast tunability, immunity to electromagnetic interference and low weight, have been widely implemented in microwave systems. Microwave phase shifters as key components in many microwave applications such as phased-array antennas [2] and microwave filters [3] have gained much interest. So far, several schemes for phase shifting including wavelength conversion [4], stimulated Brillouin scattering [5], and slow-light effects in semiconductor devices [6,7] have been reported. Recently, silicon ring resonators were also used as phase shifter to realize a 0 - 260° phase-shifting range [8]. In this paper, we demonstrate a tunable microring resonator based phase shifter with a larger phase-shifting range of 0 - 315° and much lower power consumption. This device is easily integrated with photonic and electronic circuits and offers stable tuning characteristics.

2. Measurement

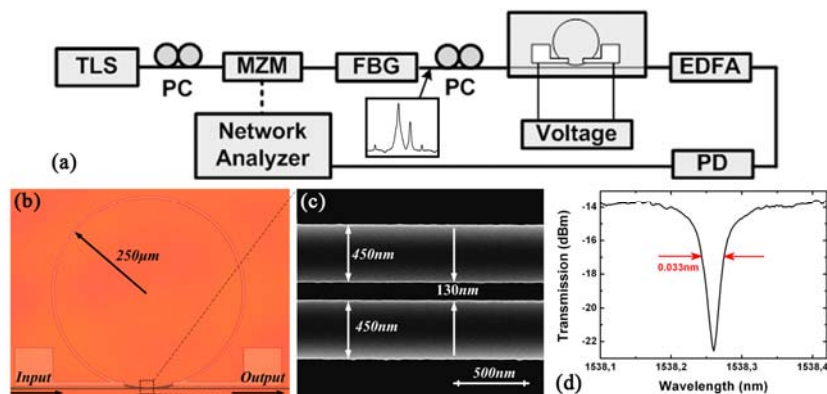


Fig. 1. (a) Experimental setup for phase shift measurements. (b) Top-view optical microscope picture of the fabricated microring resonator with micro heater. (c) Scanning electron micrograph picture of the coupling region between the waveguide and the microring. (d) Transmission spectrum of the microring resonator around 1538nm for TM mode.

The experimental setup used to measure the microwave phase shift with a microring resonator is schematically shown in Fig. 1(a). Light from a tunable laser source (TLS) was modulated through a Mach-Zehnder modulator (MZM) by a microwave signal from the network analyzer. A fiber Bragg grating (FBG) filter was used to filter out one of the sidebands of the modulated signal. After that, the optical signal, with the envelope modulated at the microwave frequency in the time domain and with two peaks of the desired frequency spacing in the optical spectral domain, was generated and sent into a microring resonator with micro heater as shown in Fig. 1(b). The microring resonator was fabricated in SOI material with a top silicon thickness of 340nm and a 1μm buried silicon dioxide. The waveguides in the device are 450nm wide and the gap between the ring and the bus waveguide is 130nm as illustrated in Fig. 1(c). The polarization of the input light was adjusted to the quasi-TM mode with a fiber polarization controller (PC). Figure 1(d) shows the transmission spectrum of the microring resonator for TM mode. The optical phase of the output field from the microring resonator experiences a π shift on resonance, and the full phase shifting range of 0 - 2π can be achieved near the resonance [8]. By applying a voltage to the micro heater, the resonance frequency of the ring can be tuned with respect to one of the peaks of the optical signal to change the

phase difference between the two peaks. Amplified by an erbium-doped fiber amplifier (EDFA), the output signal was detected by a high-speed photo detector (PD). Due to the beating between the two optical frequencies at the high-speed PD, the optical phase change will be finally converted to the microwave signal. Then the network analyser was used to extract the information of phase and power changes of the microwave signal carried by the optical beam.

A microring resonator with 0.033nm 3-dB bandwidth (quality(Q)-factor $\sim 46,000$) was first tested in the experiment. Figure 2(a) shows the measured maximum phase shifts with different microwave frequencies modulated on the optical beam. The maximum phase shift increases linearly as the frequency increases. The measured RF phase shift and RF power variation as a function of applied electrical power to the micro heater is also shown in Fig. 2(b). A continuously tunable RF phase shift, through changing the applied electrical power, is demonstrated, and the maximum RF phase shift of 315° for a microwave frequency of 15GHz is achieved. However, the relatively large RF power variation (about 7dB) due to the high extinction ratio of the resonator hampers the application as a phase shifter. These problems can be resolved by using a lower Q-factor microring resonator with lower extinction ratio. We also tested another ring resonator with 6dB extinction ratio and ~ 0.067 nm 3-dB bandwidth which corresponds to a lower Q-factor of 23,000. The RF power variation is ~ 5 dB smaller than the high-Q ring resonator (see Fig. 2(c)). Though the maximum phase shift of $\sim 205^\circ$ is smaller than that of high Q ring resonator, the phase shift is more linear. The small power variation and phase shifting linearity with applied control power make the lower Q ring resonator a more practical option for the microwave applications.

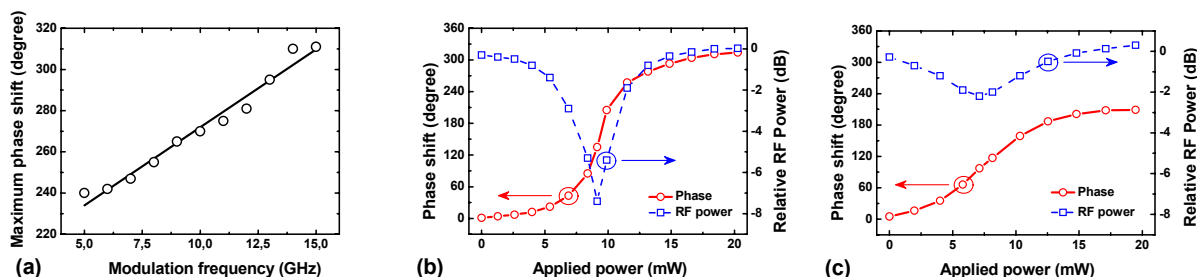


Fig. 2. (a) Measured maximum RF phase shift versus the microwave frequencies with the microring resonator of 46,000 Q-factor. (b,c) Measured RF phase shift and relative RF power versus the applied power to the micro heater on the microring resonator with a Q-factor of 46,000 (b) and 23,000 (c).

Compared to the device in [8] where the microring resonator was tuned by a strong optical power, our device is more energy efficient and offers larger phase shift and simpler control. Only a small electrical power of 11mW is needed to obtain $\sim 260^\circ$ (~ 4.6 rad) phase shift which is one third of the optical power in the previous device. In addition, our device can be easily cascaded and controlled independently to realize a relatively linear full 2π phase shift (360°).

3. Conclusion

We have introduced electrically tunable SOI microring resonator based microwave phase shifters. A phase shifting range of 0 - 315° has been achieved at a microwave frequency of 15GHz with a microring resonator of 46,000 Q-factor. A smooth phase shift of up to 205° has also been demonstrated with only ~ 2 dB RF power variation for a microring resonator of 23,000 Q-factor. The results indicate that it is possible to realize a continuously tunable 360° RF phase shifter with small power consumption by cascading two microring resonators.

4. Reference

- [1] J. Capmany and D. Novak, "Microwave photonics combines two worlds", *Nature Photonics*, 1, 319 (2007).
- [2] S. Tonda-Goldstein, D. Dolfi, A. Monsterleet, S. Formont, J. Chazelas and J.P. Huignard, "Optical signal processing in radar systems", *IEEE Trans. Microw. Theory Tech.*, 2006, 54, pp. 847–853.
- [3] J. Capmany, B. Ortega, D. Pastor and S. Sales, "Discrete-time optical processing of microwave signals", *J. Lightwave Technol.*, 2005, 23, pp. 702–723.
- [4] M. R. Fisher and S. L. Chuang "A microwave photonic phase-shifter based on wavelength conversion in a DFB laser," *IEEE Photon. Technol. Lett.*, vol. 18, pp. 1714, Aug. 15, 2006.
- [5] A. Loayssa and F. J. Lahoz "Broad-band RF photonic phase shifter based on stimulated Brillouin scattering and single-sideband modulation," *IEEE Photon. Technol. Lett.*, vol. 18, pp. 208, Jan. 1, 2006.
- [6] W. Xue, Y. Chen, F. hman, S. Sales, and J. M rk, "Enhancing light slow-down in semiconductor optical amplifiers by optical filtering," *Optics Letters*, vol. 33, May. 2008, pp. 1084-1086.
- [7] W. Xue, S. Sales, J. Capmany, and J. Mørk, "Microwave phase shifter with controllable power response based on slow- and fast-light effects in semiconductor optical amplifiers," *Optics Letters*, vol. 34, Apr. 2009, pp. 929-931.
- [8] Q. Chang, Q. Li, Z. Zhang, M. Qiu, T. Ye, and Y. Su, "A Tunable Broadband Photonic RF Phase Shifter Based on a Silicon Microring Resonator," *Photonics Technology Letters, IEEE*, vol. 21, 2009, pp. 60-62.